CHAPTER 4
DEVELOPMENT OF STANDARDS
FOR THE HDVIP AND PSI PROGRAM

4.1 STANDARD SETTING REQUIREMENTS

Assembly Bill 584 specifies that the HDVIP adopt the SAE J1667 test procedure and measurement methods. However, SAE does not suggest or recommend pass/fail standards for smoke opacity, as it is up to the regulating agencies to decide on the stringency of such standards. At the same time, AB 584 requires that no vehicles be failed incorrectly. The specific language of the legislation is as follows:

(1) The smoke standards and procedures shall be designed to ensure that no engine will fail smoke test standards and procedures when the engine is in good operating condition and is adjusted to manufacturer's specifications.

(2) In implementing this section, the state Board shall immediately adopt procedures that either ensure there will be no false failures, or that ensure that the state Board will remedy any false failures without any penalty to the vehicle owner.

Under the previous program conducted by California, pass/fail standards were set by reference to the Federal Smoke Test Procedure (40 CFR, Section 86-884) used for certification of new engines to the EPA standards for smoke opacity. Smoke opacity measured on the snap acceleration test was linked to smoke opacity measured on the "rolling acceleration" test, which, in turn, was linked to smoke opacity measured on the acceleration phase of the Federal Smoke Test Procedure. This complex linkage was needed because no data was available for a sample of diesel engines tested on the Federal Smoke Test Procedure and on the snap acceleration test. However, the linkage between these smoke opacities remains controversial. Separately, the SAE J1667 procedure explicitly states that it is not intended to correlate the Federal Smoke Test.

As a result, a new frame of reference was developed for the SAE J1667 procedure that allows definition of what constitutes a "failure" to meet applicable standards. In this revised definition, the presence of any observable and correctable malperformance in the engine is used as a criterion to gauge whether a particular vehicle is passed or failed incorrectly. It is to be noted that the criterion is not explicitly linked to the magnitude of the emissions effect of any specific malperformance, although most malperformances affecting an engines' smoke opacity on the snap acceleration test will affect engine emissions on the Federal Test Procedure. (It may also be true that an engine with no observable or correctable malperformance can have emissions higher than standards it is certified to, but the magnitude of the increase in such cases is expected to be small.)

The malperformance based criterion then leads to specific definitions for properly failed and improperly failed vehicles. For any specific smoke opacity standard using the J1667 procedure, an improperly failed vehicle (or an error of commission) is one which exceeds the smoke opacity standard on the J1667 procedure, but cannot be diagnosed to have malperformances that, when corrected, do not reduce smoke opacity enough to meet the standard. A correctly failed vehicle, in contrast, can be repaired to meet the applicable smoke opacity standard after repairs.

The adoption of malperformance based criteria then directly links compliance with standards to the ability to repair such vehicles to meet standards. The objectivity of such a criterion could then depend on (1) the competence of the mechanic performing the repair and (2) the ability to maladjust the engine calibration to such a degree that it meets the specified smoke standard on the J1667 test but it falls outside the range of allowable calibrations, as specified by the manufacturer, to meet other criteria such as durability and driveability. The first issue of mechanic competence is avoided by referring diagnosis and repairs to dealerships and factory authorized personnel, at least in theory. The second issue of maladjustment is avoided by placing the additional restriction that the engine must be within manufacturer specifications after repair, per the legislative intent.

4.2 TRS IMPLEMENTATION

The actual Truck Repair Study as implemented departed from the established study parameters as summarized in Chapter 3 for two reasons. First, recruitment of vehicles for the study proved much more difficult than envisioned. Many engine makes/models in the required opacity ranges of interest (per the sample design) could not be found, and hence, the original sampling plan was not strictly followed. Second, extensive delays in the approval of SAE J1667 by the SAE committee lead to delays in starting the study. Available resources permitted the recruitment and repair of 71 trucks. As a result of the difficulty in recruiting trucks, the sample contained very few medium duty trucks. Vehicles were recruited in both Northern and Southern California, with each area using a different brand of SAE J1667 meters for recruitment.

The difficulty in truck recruitment also led to some relaxation of the vehicle qualification criteria as the study proposed. Initially, the test protocol required that dealership opacity measurement match the field test measurement within ±5 opacity points. However, it became apparent that this criterion was too restrictive. The scheduling of potential recruits for repairs at dealerships was a time consuming process and often several weeks elapsed between the initial ARB field test and the test at the dealership location. Over this period of time some vehicles had experienced further engine deterioration, and some owners had performed minor repairs (e.g. changing the air cleaner) so that the ±5 opacity points match requirements could not be enforced. While this requirement was not met by several vehicles in the sample, the average for the initial field test and the acceptance test at the dealership were within the requirement, because the opacities were both higher and lower at the dealership relative to the measured opacity at the field test.

Eight trucks were rejected at the dealership based on qualification criteria. Five of the eight were due to extreme engine wear, and only a full rebuild would have restored these engines to specifications. In three cases however, the measured opacity at the dealership was below acceptance criteria of at least 40 percent opacity (for pre-1991 engines). One of these engines was not field tested, but the other two bear discussion.

Both the engines that displayed unusual field behavior were DDC 8V-71 engines that were relatively old (1974 and 1981 model year). Both engines tested at relatively high opacities in the field (73.5 percent and 59.3 percent) but were below 30 percent opacity when tested at the dealerships. ARB staff conducted follow-up reviews on these engines and were able to document excessive variability in measured smoke emissions after a few minutes of idle time between successive J1667 measurements. Large changes in smoke opacity of over 20 percent are indicative of malfunctions in the throttle delay system, or other fuel system controls, since other 8V-71 engines did not display such behavior. However, in the absence of actual repair data, we cannot confirm the hypothesis of malfunctions in the throttle delay system.

Dealership repairs were selected during program design as it was believed that problem diagnoses and repair effectiveness issues would be minimized. However, it was found that the quality of diagnostics and repair varied between dealerships during the course of this study. In the sample of 71 vehicles, 9 vehicles had to be subjected to more than one repair cycle due to incorrect or incomplete diagnosis by the dealership. In addition, three vehicles were not adequately repaired, one because the owner was unwilling to wait for additional repairs, the second, because a serious parts mismatch was discovered that would require very expensive repairs not covered by the budget, and the third because the engine would have required a rebuild. Hence, some results are presented based on the 68 repaired engines and others based on the entire 71-engine sample. A comprehensive Listing of all vehicles in the study, and a summary of their repair is included as Exhibit 4-1 at the end of

this section.

Documentation of the actual repairs performed was not at the level expected since some mechanics filled out the forms incompletely or not in fully-understandable ways. Nevertheless, attempts were made to reconstruct the details on repairs performed by contacting mechanics on the telephone when the data was incomplete. Hence, available data on repairs is reasonably complete, although diagnostic related time and expenses are less well understood, as explained in Chapter 5. A final post-repair opacity measurement conducted by ARB staff is available for all vehicles in the sample, so that pre-repair and post-repair data on smoke opacity is comprehensive and complete. Post-repair smoke opacities for all three pre-1991 model year groups are at 20 $\pm$ 2 opacity points, a finding that suggest that older (pre-1980) engines can meet smoke opacity standards of the same stringency as 1980 to 1990 engines. This finding of similar behavior is also consistent with the technological similarity of engines built during the 1974 to 1990 time frame, a period over which most engines had evolutionary, not revolutionary improvements. Analysis of failure rates by model year also suggest that all 1990 and earlier trucks can be modeled as one population, as detailed in Section 5 of this TSD.

4.3 ANALYSIS OF RESULTS

The sample of 63 pre-1991 engines (including those that were not fully repaired) were well distributed over the opacity range for the initial field test opacity. As shown by the data below, the sample is almost evenly represented over the opacity range, except in the 75 to 85 percent opacity range, so that cutpoints can be selected in the 40 to 65 percent opacity range with reasonable sample representation. The distribution of the pre-1991 engine sample by opacity range for pre-repair opacity is as follows:

Opacity Range	Sample %
35 to 45	15.87

45 to 55	17.46
55 to 65	15.87
65 to 75	26.99
75 to 85	4.76
85+	19.05

The selection of the pass/fail cutpoints for pre-1991 engines should ideally be based on the optimization of the errors of commission and omission, as per the previous TSD for the HDVIP. However, the new legislative language requires that ARB developed procedures so that <u>no</u> engine will fail smoke standards and procedures when the engine is in good operating condition and set to manufacturers specification. Given the restrictive language of the legislation, selection of standards is based on a zero error of commission rate.

The post-repair smoke opacity is shown as a function of the pre-repair smoke opacity in Figure 4-1, for pre-1991 engines. Only the three incompletely repaired trucks have smoke opacity levels after repair over 40 percent. Post- repair smoke opacity is also clearly shown by Figure 4-1 to <u>not</u> be a function of pre-repair smoke opacity, i.e., the severity of the malperformance has no impact on how well the engine can be repaired. The post-repair opacity distribution is as follows for pre-1991 vehicles.:

Opacity Range	Sample %
5 to 10	6.3
10 to 15	23.8
15 to 20	17.5
20 to 25	15.9
25 to 30	20.6
30 to 35	6.3
35 to 40	4.8
40 +	4.8 (Not fully repaired)

As can be seen from the above distribution, the majority of the engines were repaired to

smoke levels below 30 opacity points. The highest post-repair smoke opacity recorded for a fully repaired engine was 38.7 percent.

The three trucks not fully repaired included: one that had been incorrectly rebuilt; a second with a very worn engine, as confirmed by excessive blowby; and a third where repairs completed did not bring the smoke opacity down as expected. In the last case, the mechanic suggested injector problems, but this could not be confirmed as the owner was unwilling to wait for further diagnostics and potential repair. This engine had a post-repair smoke opacity of 47 percent, while the very worn engine has a post-repair smoke opacity of 49.8 percent. Under a very conservative analysis, one could consider the engine with possible injector problems as the highest post-repair value for an engine in "good working order" since the problems remain unconfirmed. One could also potentially argue that the acceptance of the "worn" engine into the program indicates it may have been marginal and the its opacity could represent the best possible post-repair value for an engine that may be nearing the end of its useful life. However, mechanic confirmation of excessive blowby provides a strong case for excluding this vehicle from the sample.

A similar opacity distribution analysis is of more limited value for the sample of 1991 and later model year engines. The sample consists of 8 vehicles, including two Isuzu NPR light-heavy duty models (such engines have not been sampled in other model year groups). The pre-repair opacities in increasing order are as follows, as measured at the dealership:

No.	Vehicle No.	Opacity
1	67	22.8
2	56	28.2
3	65	29.2
4	70	30.3
5	63	31.3

6	**71**	**38.8**
7	**43**	**43.4**
8	**4**	**57.5**

Measurements at the dealership location rather the field location are listed for smoke opacity above, since not all vehicles had a field test in this sample.

It should be noted that pre-repair smoke opacities recorded in the field varied significantly (by more than 5 opacity percent) in two cases. Post repair smoke opacity values were as follows:

No	Vehicle No.	Opacity
1	56	11.0
2	4	15.1
3	67	18.9
4	70	19.2
5	65	20.5
6	43	25.6
7	71	28.5
8	63	30.6

The post-repair smoke opacity of the small sample appears relatively high. For example, no engines were repaired to below 10 percent opacity unlike the pre-1991 model year sample. In addition, two engines (on vehicle 63 and 67) showed virtually no smoke opacity reduction after repair. (i.e., the pre- and post-repair smoke opacities differed by less than 5 percent).

Indeed, the repair records on the 1991+ engines indicate some mechanics to be unfamiliar with electronic systems (see Chapter 5) The results of the small sample are at odds with the fact that most 1991+ vehicles have very low smoke emissions, and certification peak smoke levels are 50 to 70 percent below certification peak smoke levels for pre-1991 engines.

4.4 SELECTION OF STANDARDS

In response to the legislative intent of AB 584, the selected standards must be such that

- **none of the vehicles repaired to "good operating condition" can fail the standard.**
- **issues regarding variability in smoke measurement must be addressed to prevent false failures.**

The first point is directly addressed using the post-repair opacity distributions.

For pre-1991 engines, a reasonable choice of the highest opacity after repair is 38.7 percent, indicating a possible range of standards above 39 percent opacity. However, the existence of one engine (repaired to 47 percent opacity) that only had unconfirmed additional malperformances could suggest that a more conservative standard be applied. For 1991+ engines, the equivalent highest post-repair value is 30.6 percent, suggesting a possible range of standards above 31 percent. It should be noted however that this is based on a largely unsatisfactory sample in terms of size and repair quality.

Another issue to be considered is one of variability of measured smoke opacity. There are three types of variability, one associated with the engine itself, the second with test performance, and the third associated with variation among different meters certified to the J1667 standard. The issue of engine variability is complex since it is dependent on the time period over which it is measured. Engines may become more variable with use and over time for reasons associated with deterioration of parts, or contamination by ambient dust or fuel impurities. As an example, an engine may initially test at one value of snap opacity, but may have a different value a few days later if the air cleaner is clogged from dust, or the vehicle is refueled with inadvertently contaminated diesel. Over longer periods, the wear of engine components can increase smoke, but engine component failure can occur anytime to increase smoke emissions. Certain types of failures can also cause smoke opacity as measured on the J1667 procedure to vary from test to test, making the measurement more variable. A key factor in this analysis is that variability associated with

these causes are not accounted for in the standard setting process as its causes are associated with correctable malperformances.

The second type of variability is associated with the engines' cycle-to cycle variability and test implementation variability, all other factors remaining constant. This variability is associated with observed differences in the J1667 smoke measurement between one snap cycle and another snap cycle conducted on an engine in good working order. In order to be sure that no in-use deterioration has taken place between one J1667 measurement and the next, the tests have to be performed within a relatively short time, using the same meter, on engines known to be in good working order. To estimate this variability, we have utilized data form the post-repair smoke opacity checks conducted by the dealership staff and by the ARB field staff. These measurements were usually conducted within a two hour time span and independent data from two tests on the same engine can be found for 25 engine in the 71 engines sample. Analysis of the paired differences between snap idle measurements for the 25 engines indicates a mean difference of -0.25 and a standard deviation (σ) of 2.25 opacity percent. In the absence of any large scale variability study, a test variability allowance of 4 to 5 opacity points representing 2σ for a 95 percent confidence level appears reasonable, to insure that no engine is failed incorrectly due to test variability.

The third issue regarding variability on the differences that can occur between different makes or models of smokemeters calibrated to the same standard. The J1667 procedure allows the use of different types of smokemeters using different techniques to measure smoke opacity. These issues were specifically addressed by the J1667 Committee. A comparison test of six smokemeters satisfying the requirements of SAE J1667 was conducted in April 1996. These smokemeters were compared on six representative heavy-duty diesel engines representing a wide variety of model years, fuel control systems, etc., and having nominal opacities ranging from 12% to 95%. The opacities of each J1667 test cycle were measures by two different models of smokemeters of different models mounted on the two sides of a split exhaust pipe. The differences between these paired opacity measurements were analyzed. The total number of pairs of opacities was 360.

The opacities measured by one of the six smokemeters on the three highest opacity engines were much different than the opacities measured by the other five smokemeters, and this smokemeter's measurements were excluded from analysis. The following statements summarize results for the other five smokemeters, which had 240 pairs of opacities. A tolerance interval for the signed values of the paired differences of their opacities was computed. This tolerance interval covers an estimated 95% of the population of absolute values of paired difference and has a 95% confidence level. The standard deviation of these paired differences is 2.4% -- i.e. with high confidence, 95% of the signed difference of paired opacities of these five meters are less than 5%. This interval implies that 95% of the pairs of opacities of a heavy-duty diesel engine measured on the same occasion by any of these five meters will differ by less than 5%, with a high level of confidence. A maximum allowance of 5% in the standard for difference between opacities measured by different meters should insure that whether a tested engine exceeds a standard or not will rarely depend upon which meter is used.

Hence, a total variability margin of 8 percent, consisting of a 5 percent allowance for meters and 5 percent allowance for engine variability, is required to ensure that the standard will not cause any error of commission, with a high level of confidence. This assumes that meter differences and engine variability are not correlated and the two margins are added as the sum of squares.

Using the reference post-repair high value of 47 percent for pre-1991 engines, and 30.8 percent for 1991+ engines, the equivalent standards should be <u>55 percent</u> and <u>40 percent</u> respectively which are identical to the standards used previously. However, in both cases, the post-repair high opacity values may not reflect complete or correct repairs and the

standards may be too conservative. It appears possible and likely that a larger sample of data on repairs especially on 1991 and later engines could lead to a significantly lower standard than the 40 percent value derived in this analysis.

Separately, it should be noted that this study sample of 71 heavy-duty vehicles obviously does not contain every possible make and model of heavy-duty diesel engine. Historically, ARB has relied on manufacturers to identify special engine certification families incapable of meeting the 55 percent or 40 percent standard, as applicable. These engine families were treated on a case-by-case basis, and ARB provided special exemptions from the standard to specific families, if justified. It is recommended that ARB continue this practice and re-examine the exempted list of families developed as a starting point to develop a new list of families exempted under the J1667 procedure.

EXHIBIT 4-1

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